Microstructure and Mechanical Properties of Powder Metallurgy Fe-Cu-Sn-Ni Alloys

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Abstract. The main purpose of the work was to determine the powder composition on the microstructure and properties of iron-based sinters used as a matrix in metallic diamond tools. Fe-Cu-Sn-Ni sinters obtained from a mixture of elemental powders were used for research. Sintering was performed using the hot-pressing technique in a graphite mold. The microstructure and mechanical properties of the sinters were investigated. The investigations of obtained sinters included density, hardness, static tensile test, X-ray analysis, microstructure, and fracture surface observations. The results obtained indicate that the sinters produced have relatively high hardness and good mechanical properties.

Introduction

Diamond blades are commonly used to cut natural stone and ceramics. The cutting section of the tools consists of synthetic diamonds embedded in a metallic matrix by powder metallurgy technology [1,2]. There are many metals that have been used as matrices of diamond-impregnated tools. In general examples of such metals are cobalt, aluminum, titanium, copper, iron, zinc, tin, and nickel. For a few years, the use of inexpensive pre-mixed and milled powders in ball mills, which may replace cobalt powders, has been observed [3,4]. Diamond-metallic compounds based on metal matrices containing iron, copper, nickel and tin possess favorable mechanical properties, relatively low sintering temperature, and low cost of materials [5,6].

Based on previous research [7], the iron-based material was designed for the matrix of metallic diamond tools. The material was obtained from elemental powders subjected to grinding for 30 h. The material was selected for the tests, with the mass fractions of individual powders as follows: 60% Fe, 23.8% Cu, 4.2% Sn, and 12% Ni. The new matrix material had a porosity not exceeding 3% and mechanical properties that would allow replacement of cobalt-based sinters [8]. The very important role of a matrix in diamond impregnated segments is to hold diamond particles as long as possible. The effective way to improve diamond retention in the matrix is through the use of diamond particles with a thin film of strong carbide obtained with coating technology [9,10].

Material and Its Mechanical Properties

The experimental powder mixtures were made from the following elemental powders (Fig. 1):

a) Höganäs NC100.24 grade, carbon-reduced iron powder (20-180 μm),
b) Vale T255 grade, carbonyl nickel powder (average size = 2.4 μm),
c) water-sprayed bronze tin powder containing 15% by mass. tin (25GR85 / 15.325 from ECKA), with a particle size below 45 μm.

The mass fractions of individual powders in the tested material FeCuSnNi were: 60% Fe, 28% bronze and 12% Ni, which corresponds to the chemical composition: 60% Fe, 23.8% Cu, 4.2% Sn, 12% Ni. Before the consolidation process, the powders were premixed in the right proportions in a Turbula mixer for 30 minutes and then milled in an EnviSense RJM-102 laboratory ball mill

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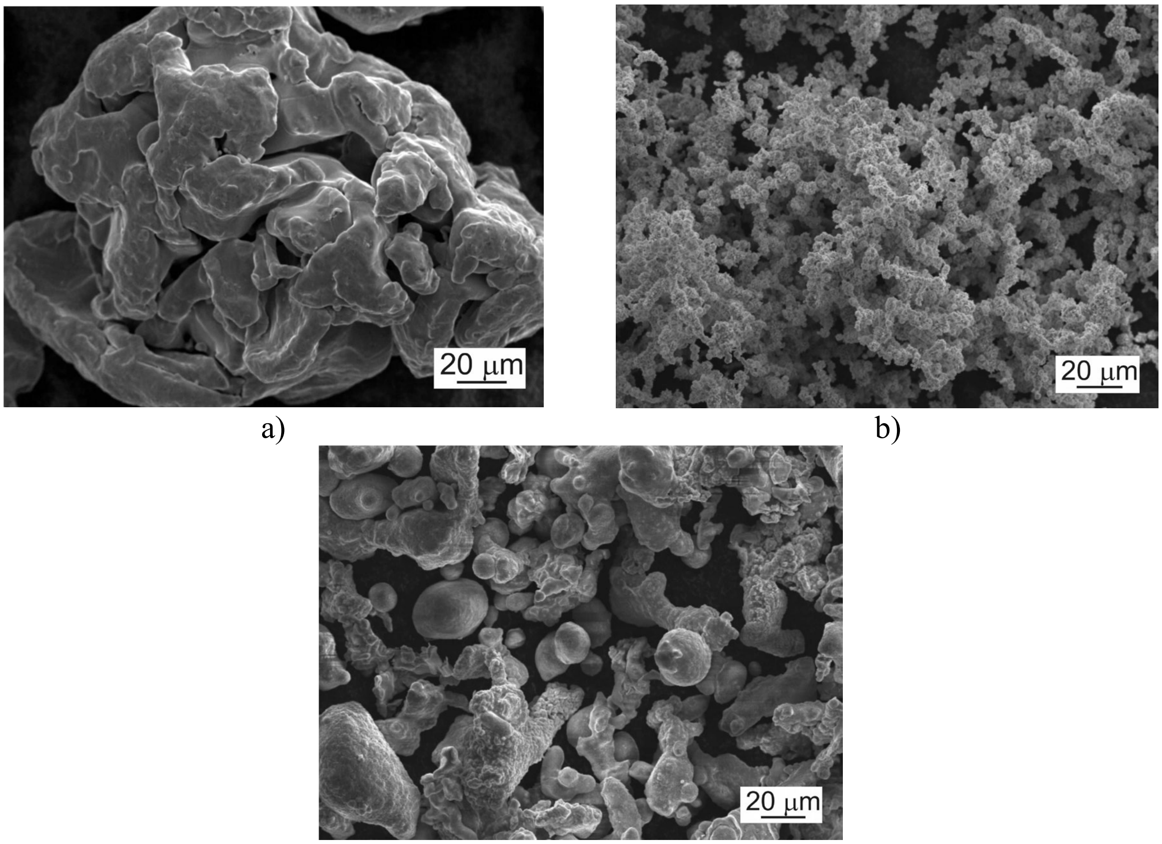
in ethyl alcohol with a small amount of glycerol. The milling vial was filled to half its volume with 100Cr6 steel balls of 12 mm diameter.

The initial mixtures of FeCuSnNi powders and ground powders of both materials were subjected to consolidation by hot pressing, in a nitrogen atmosphere, using the Unidiamond press furnace Idea (Italy), within 30 hours. The prepared mixtures were pressed in a graphite matrix, allowing the simultaneous production of 4 samples with nominal dimensions of 7 x 6 x 40 mm. A temperature of 900°C and a pressure of 25 MPa were used for sintering the material.



a) b) c)

Fig. 1. *Powders used for research, a) iron powder NC100.24, b) nickel powder T255, c) tin bronze powder 25GR85 / 15.325*

Table 1. *Physical Properties of the Material*

Material	Density, [g/cm^3]	Porosity, [%]	HV10	oxygen content, [% mas.]
FeCuSnNi, without milling	8.000 ± 0.028	2.20 ± 0.20	241.7 ± 15.4	0.34 ± 0.03
FeCuSnNi, milling 30 h	8.008 ± 0.037	2.20 ± 0.40	272.7 ± 8.4	0.59 ± 0.01

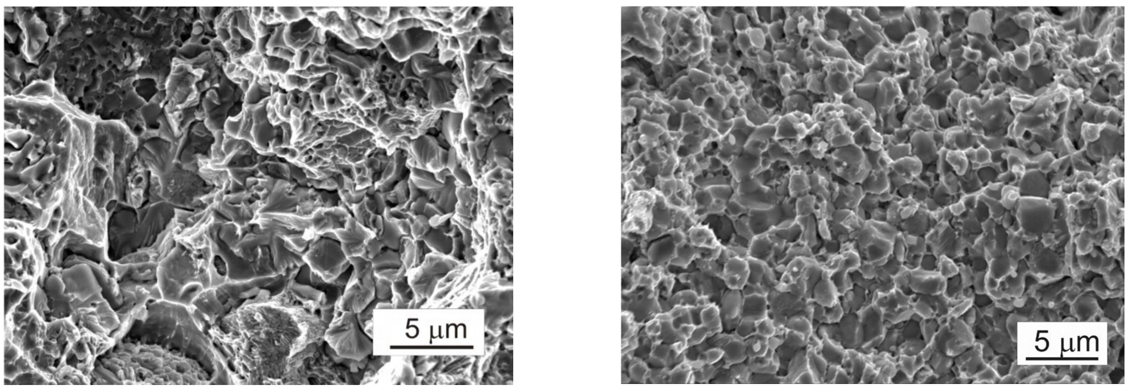
Table 2. *Mechanical Properties of the Material*

Material	Elastic modulus E [GPa]	Poisson ratio v	Yield Strength $R_{p0,2}$ [MPa]	Tensile strength R_m [MPa]	Relative elongation ε [%]
without milling			169+/-10	481.1+/-15.6	7.5+/-0.2
milling 30h	165 +/- 3	0.32	273+/-12	739.4+/-20.5	11.0+/-0.5

The static tensile test was carried out using a Universal Testing Machine UTS-100 with an automatic control and data recording system from Zwick. Based on the recorded data, the following were calculated: yield strength $R_{p0.2}$, tensile strength *Rm,* and relative elongation ε. The parameters mentioned above were determined as the arithmetic mean of three tensile tests. The elastic modulus E and the Poisson ratio v were also measured by ultrasound using a Panametrics Epoch III flaw detector. The sinters obtained from powders after milling show a higher hardness and a clearer tensile strength compared to sinters made from powders without milling.

Fractography of Fracture

Fractographic tests were performed on the fracture obtained in the tensile test. Research was carried out using the JSM-7100F scanning electron microscope, integrated with the OINA-AZtec X-ray microanalysis system.



a) b)

Fig. 2. *Surface fracture of FeCuSnNi sinter samples obtained from powders a) without milling, b) after milling for 30 h*

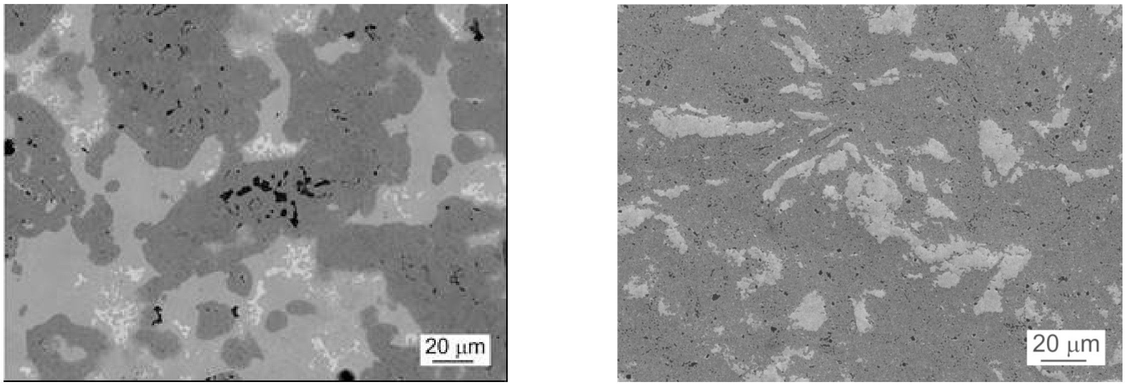
Observations of the fracture surfaces lead to the conclusion that, for all sinters of the tested materials without milling, the fracture is brittle and transcrystalline. Cracking occurs at the grain boundaries. The mechanism of fracture is mixed. On the other hand, for sinters made from powder mixtures, after a grinding time of 30 h, there is a fracture surface developed. The fractures take a ductile form; only areas showing the features of an intercrystalline fracture are visible in places.

Microstructure Studies

Observations of the microstructure of the produced sinters were carried out using the JSM-7100F scanning electron microscope, integrated with the X-Max-AZtec series EDS microanalysis system from OXFORD INSTRUMENTS. The tests were carried out using a backscattered electron detector. The microstructure of the FeCuSnNi sinter, obtained from powder mixtures without milling and after milling 30 h (Fig. 3).

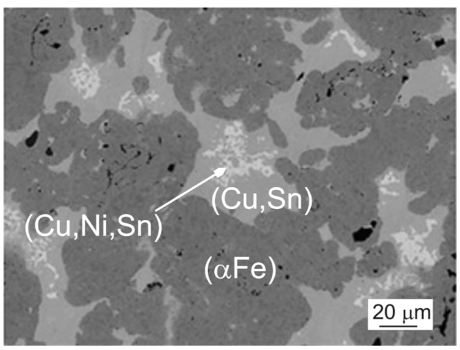
The FeCuSnNi sinter revealed a complex phase structure (Fig. 4). Point chemical analysis showed the presence of Fe solution,, Cu solution and iron oxides (Fig. 5). Nickel atoms were distributed throughout the entire sinter volume with a distinct advantage in the white phase (Fig. 6). The oxides were concentrated in the region of the iron solution. For FeCuSnNi sinters obtained from powders without milling and after 30 h of milling, the chemical composition of the point and the surface distribution of the elements are shown in Fig. 4…Fig.7.

In the area rich in iron, there are also Ni atoms, which easily integrate into the network of Fe atoms because nitrogen has similar sizes of atomic radii.



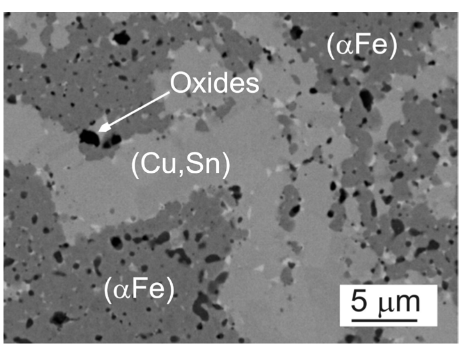
a) b)

Fig. 3. *Microstructure of sinters made of FeCuSnNi powder,*
a) not subjected to the milling process, b) subjected to milling for 30 h,



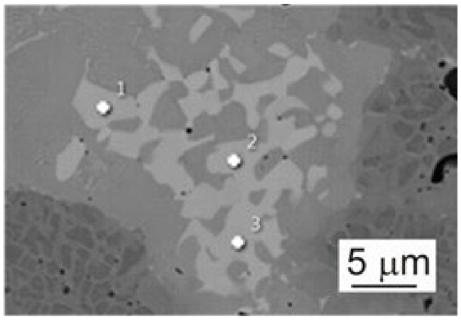
	O [%]	Fe [%]	Cu [%]	Sn [%]	Ni [%]
(Fe)		85.73	4.56	0.34	9.37
(Cu)		3.26	85.55	5.65	5.54
Oxides	15.12	72.64	3.33	2.05	6.86

Fig. 4. *Microstructure of the FeCuSnNi sinter (without milling) and the results of the microanalysis (wt%) (from the X-ray spectra) collected from the areas: Fe solution, Cu solution and the area of iron oxides*



	O [%]	Fe [%]	Cu [%]	Sn [%]	Ni [%]
(Fe)	-	72.59	10.54	0.93	15.94
(Cu)	-	5.24	78.04	11.32	5.40
Oxides	17.18	71.64	1.97	0.75	8.46

Fig. 5. *Microstructure of FeCuSnNi sinter (milling 30 h) and the results of the microanalysis (wt%) (from the spectra of X-rays) collected from the areas: Fe solution,, Cu solution and the area of iron oxides.*



	Fe [%]	Cu [%]	Sn [%]	Ni [%]
1	1.59	28.20	38.47	31.74
2	2.04	29.28	36.03	32.65
3	2.30	26.17	38.09	33.44

Fig. 6. *Microstructure of the FeCuSnNi sinter (without milling) with the chemical composition of the point.*

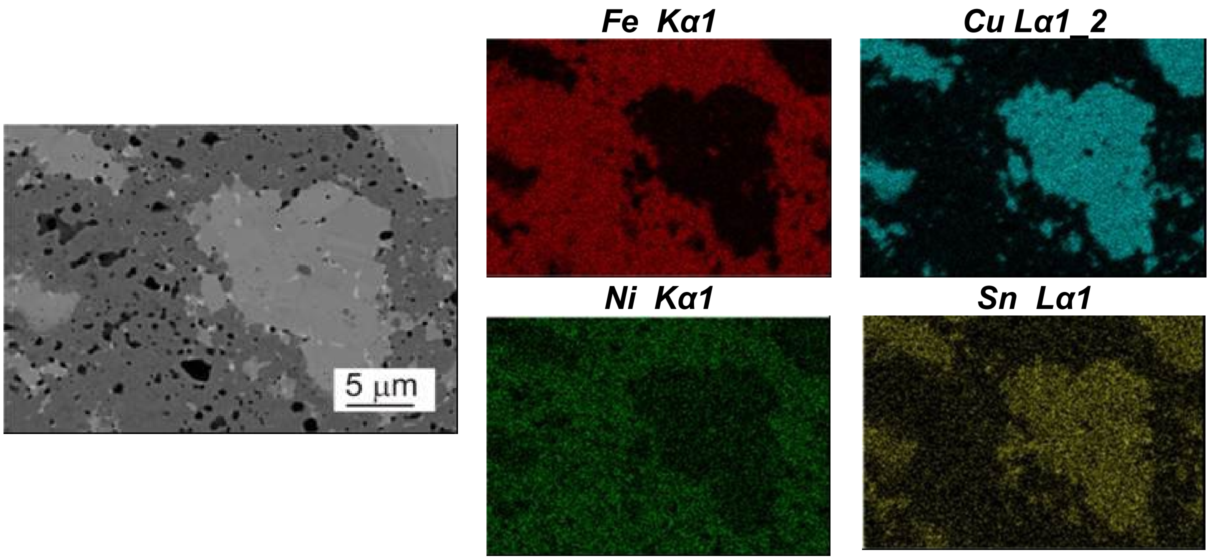


Fig.*7. Surface distribution of elements in FeCuSnNi sinter, obtained from powder mixtures after milling for 30 h*

Additionally, a detailed point analysis of the white chemical composition of the area in white was performed. The conducted analysis showed the presence of an intermetallic relationship of copper, nickel, and tin.

Conclusions

Research shows that the milling process causes greater fragmentation of the microstructure of the tested sinters (Figs. 3 and 7). The microstructure of the sinter obtained from mixtures without milling, also after 30 hours of milling, is heterogeneous. The large areas of iron solution are noticeable in microstructure, in which greater amounts of nickel were found (Fig. 7). Hence, it can be concluded that nickel diffusion proceeds into the iron solution.

The microstructures of the milled sinters obtained from the mixes milled through 30 h show distinctive features. There is a banding and lamellar structure, which is due to the flake shape of the powder particles. In the microstructure of the FeCuSnNi alloy made of the unmilled powder mixture, there is a white phase that clearly decreases after 30 h of milling. A point analysis of the chemical composition of this phase showed a high concentration of copper, tin and nickel. Analysis of chemical composition shows that it is the intermetallic phase $(CuNi)_3Sn$. In the milling process, nickel is dissolved in bronze, and tin diffuses into the iron solution (Fig. 7). The introduction of a tin bronze addition, instead of copper, to Fe and Ni powders resulted in the obtaining of a liquid phase (> 798°C) during the hot pressing process, which helped to consolidate and intensify the diffusion of the phase components.

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